Physics 20–30

Program Outcomes

Resource Development Draft

March 2004

Note: The philosophy and rationale that relates to these outcomes is in the <u>Secondary Science Revisions Program Introduction</u>. Links to the various frameworks within that document are identified in bold with parentheses **( )** and square brackets **[ ]** after the program outcomes.

This resource development draft of the program outcomes was initiated based on information collected during the secondary science needs assessment conducted in 1998. It was developed under the guidance of the Alberta Learning Science Interbranch Team with advice from the Science 10–12 Advisory Committee made up of teachers and education stakeholders from across the province. Additional revisions were made based on responses to a questionnaire and other [illegible]ns. First Nations, Métis and Inuit (Aboriginal) perspectives have yet to be infused [illegible]gram. Further changes may occur after field validation.

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Physics 20

Physics 20 consists of four units of study:
A. Kinematics
B. Dynamics
C. Periodic Motion
D. Conservation of Energy

Attitude Outcomes for Physics 20

Students will be encouraged to develop positive attitudes that support the responsible acquisition and application of knowledge related to science and technology. The following attitude outcomes are to be developed throughout the Physics 20 program, in conjunction with the outcomes for Knowledge, Science, Technology and Society (STS) and Skills in each unit.

Interest in Science

Students will be encouraged to:
show interest in science-related questions and issues and confidently pursue personal interests and career possibilities within science-related fields, e.g.,
- *express interest in science and technology topics not directly related to their formal studies*
- *appreciate the usefulness of models and theories in helping to explain the natural world*
- *recognize the usefulness of being skilled at mathematics and problem solving.*

Mutual Respect

Students will be encouraged to:
appreciate that scientific understanding evolves from the interaction of ideas involving people with different views and backgrounds, e.g.,
- *consider more than one perspective when formulating conclusions or solving problems*
- *recognize that theories develop as a result of the sharing of ideas by many scientists.*

Scientific Inquiry

Students will be encouraged to:
seek and apply evidence when evaluating approaches to investigations, problem solving and decision making, e.g.,
- *appreciate how scientific problem solving and the development of new technologies are related*
- *critically assess their opinion of the value of science and its applications*
- *appreciate the creativity and perseverance required to develop workable solutions to problems*
- *appreciate the restricted nature of evidence when interpreting observed phenomena*
- *tolerate uncertainty in providing explanations and theoretical definitions.*

Collaboration

Students will be encouraged to:
work collaboratively in planning and carrying out investigations and in generating and evaluating ideas, e.g.,

- *evaluate the ideas of others objectively*
- *assume a variety of roles within a group, as required*
- *accept responsibility for any task that helps the group complete an activity*
- *seek the point of view of others and consider a variety of perspectives*
- *develop a willingness to try various problem-solving strategies and risk being wrong.*

Stewardship

Students will be encouraged to:
demonstrate sensitivity and responsibility in pursuing a balance between the needs of humans and a sustainable environment, e.g.,

- *develop an awareness that the application of technology has risks and benefits*
- *remain critical-minded regarding the short- and long-term consequences of human actions*
- *consider a variety of perspectives when addressing issues, weighing scientific, technological and ecological factors.*

Safety

Students will be encouraged to:
show concern for safety in planning, carrying out and reviewing activities

- *consider safety a positive limiting factor in scientific and technological endeavours*
- *keep the workstation uncluttered, with only appropriate laboratory materials present*
- *treat equipment with respect.*

Unit A: Kinematics

Themes: Change and Systems

Overview: In this unit, students investigate change in position and velocity of objects and systems in a study of kinematics.

This unit builds on:
- Science 7, Unit D: Structures and Forces
- Science 8, Unit D: Mechanical Systems
- Science 10, Unit B: Energy Flows in Technological Systems.

This unit prepares students for further study of dynamics, Newton's laws, and moving particles in electric and magnetic fields in subsequent units and physics courses. This unit will require approximately 15% of the time allotted for Physics 20.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• trigonometric ratios and triangle solutions	Pure Mathematics 10, specific outcomes 6.1 to 6.3; Applied Mathematics 10, specific outcomes 6.1 to 6.3
• properties of the linear functions	Pure Mathematics 10, specific outcome 4.6; Applied Mathematics 10, specific outcomes 5.1, 5.2 and 5.7
• graphing quadratic functions and solving quadratic equations	Pure Mathematics 20, specific outcomes 2.3 and 2.4; Applied Mathematics 20, specific outcomes 2.1 and 2.3
• horizontal and vertical components of vectors, vector addition	Pure Mathematics 10, specific outcomes 6.1 and 6.2; Applied Mathematics 30, specific outcomes 5.1 to 5.4

Focusing Questions: How do changes in position, velocity, and acceleration allow us to predict the paths of moving objects and systems? How do the principles of kinematics influence the development of new mechanical technologies?

General Outcomes: There is one major outcome in this unit:

Students will:
1. describe motion in terms of displacement, time, velocity, and acceleration.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.
- scalar quantities
- vector quantities
- uniform motion
- uniformly accelerated motion
- two dimensional motion

General Outcome 1: *Students will* describe motion in terms of displacement, time, velocity, and acceleration.

Outcomes for Knowledge

Students will:

20–A1.1k define, qualitatively and quantitatively, displacement, velocity and acceleration

20–A1.2k define operationally, compare and contrast scalar and vector quantities

20–A1.3k explain, qualitatively and quantitatively, uniform and uniformly accelerated motion when provided with written descriptions and numerical and graphical data

20–A1.4k interpret, quantitatively, the motion of one object relative to another using displacement and velocity vectors

20–A1.5k explain, quantitatively, two-dimensional motion in a horizontal or vertical plane using vector components.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

20–A1.1sts explain that the goal of science is knowledge about the natural world, e.g.,

- *identify common applications of kinematics, e.g., determining the average speed of a run, bike ride or car trip, the acceleration required to launch an aircraft from a carrier* **(NS1)**

20–A1.2sts explain that scientific knowledge is subject to change as new evidence comes to light and as laws and theories are tested and subsequently restricted, revised or reinforced, e.g.,

- *analyze lunar free-fall as illustrated in a video* **(NS4)**

20–A1.3sts explain that the process for technological development includes testing and evaluating designs and prototypes on the basis of established criteria, e.g.,

- *investigate the application of kinematics principles in, e.g., the determination of the appropriate length of airport runways, the design of merging lanes, the timing of traffic lights* **(ST5d)**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 1: *Students will* describe motion in terms of displacement, time, velocity, and acceleration.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

20–A1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by:

- identifying, defining and delimiting questions to investigate, e.g.,
  - *what are the relationships among acceleration, displacement, velocity, and time?* **(IP–NS1)**.

Performing and Recording

Students will:

20–A1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an experiment to demonstrate the relationships among acceleration, displacement, velocity and time using available technologies, e.g.,
  - *interval timers, photo gates* **(PR–NS2, 3) [ICT F1–4.2, C1–4.2]**
- collecting information from various print and electronic sources to explain the use of kinematics concepts, e.g.,
  - *in the synchronization of traffic lights* **(PR–ST1, 2) [ICT C1–4.1]**.

Analyzing and Interpreting

Students will:

20–A1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- constructing graphs to demonstrate the relationships among acceleration, displacement, velocity and time for uniform and uniformly accelerated motion **(AI–NS2) [ICT C7–4.2]**
- analyzing a graph of empirical data to infer the mathematical relationships among acceleration, displacement, velocity and time for uniform and uniformly accelerated motion **(AI–NS2) [ICT C7–4.2]**
- solving, quantitatively, projectile motion problems near Earth's surface, ignoring air resistance **(AI-NS3) [ICT C6-4.1. F1-4.2]**
- relating acceleration to the slope, and displacement to the area under a velocity-time graph **(AI–NS 2,6) [ICT C7–4.2]** and, e.g., by
- *analyzing uniform motion examples using computer simulations* **(AI–NS3) [ICT F1–4.1]**.

Communication and Teamwork

Students will:

20–A1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by

- using appropriate SI notation, fundamental and derived units and significant digits **(CT–ST2) [ICT P4–4.3, F1–4.3]***
- using the delta notation correctly when describing changes in quantities **(CT–ST2) [ICT P4–4.3, F1–4.3]***.

* To be developed throughout the course

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Unit B: Dynamics

Themes: Change and Systems

Overview: In this unit, students investigate causes of changes in the position and velocity of objects and systems in a study of dynamics and gravitation. The concept of fields is introduced in the explanation of gravitational effects.

This unit builds on:
- Science 7, Unit D: Structures and Forces
- Science 8, Unit D: Mechanical Systems
- Science 10, Unit B: Energy Flows in Technological Systems
- Physics 20, Unit A: Kinematics

This unit prepares students for further study of Newton's laws and periodic motion in Physics 20 and particles in electric and magnetic fields in Physics 30. This unit will require approximately 25% of the time allotted for Physics 20.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• properties of the linear function	Pure Mathematics 10, specific outcome 4.6; Applied Mathematics 10, specific outcomes 5.1, 5.2 and 5.7
• graphing quadratic functions and solving quadratic equations	Pure Mathematics 20, specific outcomes 2.3 and 2.4; Applied Mathematics 20, specific outcomes 2.1 and 2.3
• graphing inverse-square functions	Applied Mathematics 10, specific outcome 3.1; Pure Mathematics 10, specific outcome 3.1
• horizontal and vertical components of vectors, and vector addition	Pure Mathematics 10, specific outcomes 6.1 and 6.2, or Applied Mathematics 30, specific outcomes 5.1 to 5.4

Focusing Questions: How does the understanding of forces help humans to improve or change their environment? How do the principles of dynamics influence the development of new mechanical technologies? What role do gravitational effects play in the Universe?

General Outcomes: There are two major outcomes in this unit:

Students will:
1. explain the effects of balanced and unbalanced forces on velocity
2. explain that gravitational effects extend throughout the Universe.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.
- Newton's laws of motion
- vector addition
- static and kinetic friction
- gravitational force
- Newton's law of universal gravitation
- gravitational field

General Outcome 1: *Students will* explain the effects of balanced and unbalanced forces on velocity.

Outcomes for Knowledge

Students will:

20–B1.1k explain that a non-zero net force causes a change in velocity

20–B1.2k apply Newton's first law of motion to explain, qualitatively, an object's state of rest or uniform motion

20–B1.3k apply Newton's second law of motion to explain, qualitatively, the relationships among net force, mass, and acceleration

20–B1.4k apply Newton's third law of motion, qualitatively, to interactions between two objects, recognizing that the two forces, equal in magnitude and opposite in direction, act on different bodies

20–B1.5k explain, qualitatively and quantitatively, static and kinetic force of friction acting on an object

20–B1.6k calculate the resultant force, or its constituents, acting on an object, using the addition of vectors graphically and algebraically by using vector components

20–B1.7k apply Newton's laws of motion to solve, algebraically, linear motion problems in horizontal, vertical and inclined planes near the surface of Earth, ignoring air resistance.

Outcomes for Science, Technology and Society (Emphasis on social and environmental contexts)

Students will:

20–B1.1sts explain that the goal of technology is to provide solutions to practical problems and that technological development includes testing and evaluating designs and prototypes on the basis of established criteria, but that the products of technology cannot solve all problems, e.g.,

- *assess the design and use of injury-prevention devices in cars and sports in terms of Newton's laws of motion* (**ST1, 5d, 6**)

20–B1.2sts explain that science and technology are developed to meet societal needs and that society provides direction for scientific and technological development, e.g.,

- *the use of seatbelts in school buses* (**STS1, 4b**)

20–B1.3sts explain that scientific knowledge and theories develop through collection of evidence through experimentation and the ability to provide an explanation, e.g.,

- *analyze the trajectory of lunar dust particles as illustrated in a video* (**NS2**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Skill Outcomes (Focus on problem solving)

Initiating and Planning

Students will:

20–B1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- identifying questions to investigate that arise from practical problems, e.g.,
  - *What are the relationships among acceleration, mass, and force acting on a moving object?* **(IP–ST1)**.

Performing and Recording

Students will:

20–B1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- conducting experiments to determine relationships among acceleration, force and mass using available technologies, e.g.,
  - *using interval timers or motion sensors to gather data* **(PR–ST3) [ICT C6–4.4]**
- researching the use of kinematics and dynamics principles in everyday life, e.g.,
  - *researching traffic accident investigations methods using the Internet and/or interviews* **(PR–ST1) [ICT C1–4.1]**.

Analyzing and Interpreting

Students will:

20–B1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- analyzing a graph of empirical data to infer the mathematical relationships among acceleration, force and mass **(AI–NS6)**
- using free-body diagrams to describe the forces acting on an object **(AI–NS1) [ICT F1–4.3]**.

Communication and Teamwork

Students will:

20–B1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* **(CT–ST2) [ICT P4–4.3, F1–4.3]**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* explain that gravitational effects extend throughout the Universe.

Outcomes for Knowledge

Students will:

20–B2.1k identify the gravitational force as one of the fundamental forces in nature
20–B2.2k describe, qualitatively and quantitatively, Newton's law of universal gravitation
20–B2.3k explain, qualitatively, the principles pertinent to the Cavendish experiment used to determine the universal gravitational constant G
20–B2.4k define field as a concept that replaces action at a distance and apply the definition to describe gravitational effects
20–B2.5k relate, using the universal law of gravitation qualitatively and quantitatively, the gravitational constant to the local value of the acceleration due to gravity
20–B2.6k predict, quantitatively, differences in weight of objects on different planets.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

20–B2.1sts explain that concepts, models and theories are often used in interpreting and explaining observations and in predicting future observations, e.g.,

- *compare apparent weightlessness and zero net gravity* **(NS6a)**
- *investigate the existence and shape of globular star clusters* **(NS6a)**
- *explain tidal forces on Earth* **(NS6a)**
- *describe the forces required to accelerate the Mars rover on Earth and on Mars* **(NS6a)**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

20–B2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- identifying, defining and delimiting questions to investigate, e.g.,
  - *What is the relationship between the local value of the acceleration due to gravity and the gravitational field strength?* **(IP–NS1)**.

Performing and Recording

Students will:

20–B2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- determining, empirically, the local value of acceleration due to gravity **(PR–NS2)**
- exploring the relationship between the local value of the acceleration due to gravity and the gravitational field strength **(PR–NS1) [ICT C7–4.2]**.

Analyzing and Interpreting

Students will:

20–B2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- listing the limitations of mass-weight determinations at different points on Earth's surface **(AI–NS4) [ICT C3–4.1]**
- treating the acceleration of gravity as uniform near Earth's surface **(AI–NS3)**.

Communication and Teamwork

Students will:

20–B2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* **(CT–ST2) [ICT P4–4.3, F1–4.3]**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Unit C: Periodic Motion

Themes: Energy and Matter

Overview: In this unit, students extend their study of kinematics and dynamics to periodic motion and uniform circular motion.

This unit builds on:
- Science 9, Unit E: Space Exploration
- Science 10, Unit B: Energy Flows in Technological Systems.
- Physics 20, Unit A: Kinematics
- Physics 20, Unit B: Dynamics

This unit prepares students for further study of mechanical waves, conservation of energy, and moving particles in electric and magnetic fields. This unit will require approximately 30% of the time allotted for Physics 20.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• properties of sinusoidal functions over a single period	Pure Mathematics 10, specific outcome 6.2; Applied Mathematics 10, specific outcome 6.2
• rewriting a formula in terms of the responding variable	Pure Mathematics 10, specific outcome 4.4; Applied Mathematics 10, specific outcome 5.1
• graphing inverse-square functions	Applied Mathematics 10, specific outcome 3.1; Pure Mathematics 10, specific outcome 3.1

Focusing Questions: Where do we observe periodic motion? What is necessary to maintain circular motion?

General Outcomes: There are two major outcomes in this unit:

Students will:
1. explain circular motion using Newton's laws of motion
2. describe the conditions that produce periodic motion.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.
- periodic motion
- simple harmonic motion
- restoring force
- oscillating spring, pendulum
- uniform circular motion
- planetary and satellite motion
- Kepler's laws
- mechanical resonance

Outcomes for Knowledge

Students will:

20–C1.1k describe uniform circular motion as a special case of two-dimensional motion

20–C1.2k explain, qualitatively and quantitatively, that the acceleration in uniform circular motion is directed toward the centre of the circle

20–C1.3k explain, quantitatively, the relationships among speed, frequency, period and radius for circular motion

20–C1.4k explain, qualitatively, uniform circular motion in terms of Newton's laws of motion

20–C1.5k explain, quantitatively, planetary, natural and artificial satellite motion, using circular motion to approximate elliptical orbits

20–C1.6k predict the mass of a celestial body from the orbital data of a satellite in uniform circular motion around the celestial body

20–C1.7k explain, qualitatively, how Kepler's laws were used in the development of Newton's universal law of gravitation.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

20–C1.1sts explain that the process of scientific inquiry includes analyzing the evidence and providing explanations based upon scientific theories and concepts, e.g.,

- *examine the role of orbital perturbations in the discovery of outer planets* (**NS5e**)
- *investigate the existence of extra-solar planets* (**NS5e**)

20–C1.2sts illustrate how science and technology are developed to meet societal needs and expand human capabilities, e.g.,

- *explain the functions, applications and societal impacts of geosynchronous satellites* (**STS1**)

20–C1.3sts analyze the principles and applications of circular motion in daily situations, e.g.,

- *use of a centrifuge in industry or research* (**ST1**)
- *motion of a car through a curve with constant speed* (**ST1**)
- *carnival or playground rides moving in horizontal and/or vertical planes* (**ST1**)
- *operation of a potter's wheel* (**ST1**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

20–C1.1s ask questions about observed relationships and plan investigations of ideas, problems, and issues by

- designing an experiment investigating the relationships among orbital speed, orbital radius, acceleration and force in uniform circular motion (**IP–NS2**)
- exploring design characteristics of structures that facilitate circular motion, e.g.
  - *How much banking is needed on a racetrack to make high-speed turns safe?* (**IP–ST1**).

Performing and Recording

Students will:

20–C1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an experiment to investigate the relationships among net force acting on an object in uniform circular motion and the object's frequency, mass, speed and path radius (**PR–NS2**).

Analyzing and Interpreting

Students will:

20–C1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- organizing and interpreting experimental data using prepared graphs or charts (**AI–NS1**) **[ICT F1–4.3]**
- constructing graphs to compare relationships among frequency, mass, speed and path radius (**AI–NS4**) **[ICT C3–4.1]**
- summarizing an analysis of the relationship among frequency, mass, speed and path radius (**AI–NS6**)
- solving, quantitatively, circular motion problems in both horizontal and vertical planes, using algebraic and/or graphical vector analysis (**AI–NS3**) **[ICT C6–4.1, F1-4.2]**.

Communication and Teamwork

Students will:

20–C1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) **[ICT P4–4.3, F1–4.3]**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* describe the conditions that produce periodic motion.

Outcomes for Knowledge

Students will:

20–C2.1k describe periodic motion in terms of period and frequency

20–C2.2k define simple harmonic motion as a motion due to a restoring force that is directly proportional and opposite to the displacement from an equilibrium position

20–C2.3k explain, quantitatively, the relationships among displacement, acceleration, velocity and time for simple harmonic motion as illustrated by a frictionless horizontal mass-spring system or a pendulum, using the small angle approximation

20–C2.4k define mechanical resonance.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

20–C2.1sts explain that the goal of science is knowledge about the natural world by

- *analyzing, qualitatively, the forces in real-life examples of simple harmonic motion,* e.g.,
  - *action of springs in vehicle suspensions* (**NS1**)
  - *mechanical resonance in cars, bridges and buildings* (**NS1**)
  - *seismic waves in the Earth's crust* (**NS1**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* describe the conditions that produce periodic motion.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

20–C2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- designing an experiment to demonstrate that simple harmonic motion can be observed within certain limits and relating the frequency and period of the motion to the physical characteristics of the system, e.g.,
  - *a frictionless horizontal mass-spring system or a pendulum* (**IP–NS2**)
- predicting the conditions required for mechanical resonance (**IP–NS3**).

Performing and Recording

Students will:

20–C2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an experiment to determine the relationship between the length of a pendulum and its period of oscillation (**PR–NS2**)
- performing an experiment to illustrate the phenomenon of mechanical resonance (**PR–NS2**)
- performing an experiment to determine the spring constant of a spring (**PR–NS2**).

Analyzing and Interpreting

Students will:

20–C2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions, e.g.,

- *relating the length of a pendulum to its period of oscillation* (**AI–NS2**) [**ICT C7–4.2**]
- *asking if the mass of the pendulum bob is a factor in its period of oscillation* (**AI–NS5**).

Communication and Teamwork

Students will:

20–C2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Unit D: Conservation of Energy

Themes: Energy and Equilibrium

Overview: In this unit, students investigate energy and equilibrium in the physical world, in a study of the conservation and transmission of energy.

This unit builds on:

- Science 8, Unit D: Mechanical Systems
- Science 10, Unit B: Energy Flows in Technological Systems.
- Physics 20, Unit A: Kinematics
- Physics 20, Unit B: Dynamics
- Physics 20, Unit C: Periodic Motion

This unit prepares students for further study of conservation laws in subsequent physics courses. This unit will require approximately 30% of the time allotted for Physics 20.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• the properties of the linear function	Pure Mathematics 10, specific outcome 4.6; Applied Mathematics 10, specific outcomes 5.1, 5.2 and 5.7
• graphing quadratic functions and solve quadratic equations	Pure Mathematics 20, specific outcomes 2.3 and 2.4; Applied Mathematics 20, specific outcomes 2.1 and 2.3
• the properties of sinusoidal functions over a single period	Pure Mathematics 10, specific outcome 6.2; Applied Mathematics 10, specific outcome 6.2

Focusing Questions: How does an understanding of conservation laws contribute to an understanding of the Universe? How can mechanical energy be transferred and transformed?

General Outcomes: There are two major outcomes in this unit:

Students will:

1. explain that work is a transfer of energy and that conservation of energy in an isolated system is a fundamental physical concept
2. describe the properties of mechanical waves and explain how they transmit energy.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.

- mechanical energy
- conservation of mechanical energy
- work-energy theorem
- isolated systems
- power
- mechanical waves—longitudinal and transverse
- universal wave equation ($v = f\lambda$)
- reflection
- interference
- acoustical resonance
- Doppler effect

General Outcome 1: *Students will* explain that work is a transfer of energy and that conservation of energy in an isolated system is a fundamental physical concept.

Outcomes for Knowledge

Students will:

20–D1.1k define mechanical energy as the sum of kinetic and potential energy

20–D1.2k determine, quantitatively, the relationships among kinetic, gravitational potential and total mechanical energies of a mass executing simple harmonic motion

20–D1.3k analyze, quantitatively, kinematics and dynamics problems that relate to the conservation of mechanical energy in an isolated system

20–D1.4k recall work as a measure of the mechanical energy transferred and power as the rate of doing work

20–D1.5k define power, qualitatively and quantitatively, as the rate of doing work

20–D1.6k describe, qualitatively, the change in mechanical energy in a system that is not isolated.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

20–D1.1sts explain that concepts, models and theories are often used in interpreting and explaining observations and in predicting future observations, e.g.,

- *estimate the energy released during a meteoritic impact with Earth's surface* (**NS6a**)
- *analyze the gravitational collapse of a star* (**NS6a**)
- *examine how a planet can provide a gravity assist to a space probe* (**NS6a**)
- *analyze the transformation of kinetic and potential energy of an orbiting object at perihelion and aphelion* (**NS6a**)

20–D1.2sts explain that the products of technology are devices, systems and processes that meet given needs but that these products cannot solve all problems, e.g.,

- *evaluate the design and efficiency of energy transfer devices in terms of the relationship among mechanical energy, work and power* (**ST6**)

20–D1.3sts evaluate whether Canadian society supports scientific and technological developments that help achieve a sustainable society, economy, and environment, e.g.,

- *investigate and report on a technology developed to improve the efficiency of energy transfer as a means of reconciling the energy needs of society with its responsibility to protect the environment and to use energy judiciously* (**STS4a**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 1: *Students will* explain that work is a transfer of energy, and that conservation of energy in an isolated system is a fundamental physical concept.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

20–D1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- designing an experiment to demonstrate the conservation of energy (**IP–NS2**), e.g.,
  - *Is energy conserved in a collision?* (**IP–NS1**).

Performing and Recording

Students will:

20–D1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information, e.g.,

- *performing an experiment to demonstrate the law of conservation of energy* (**PR–NS2**)
- *researching the development of the law of conservation of energy, using library and Internet sources* (**PR–NS1**) [**ICT C7–4.2**].

Analyzing and Interpreting

Students will:

20–D1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- using free-body diagrams to organize and communicate solutions to work-energy theorem problems (**AI–NS1**) [**ICT F1–4.3**]
- solving, quantitatively, kinematics and dynamics problems, using the work-energy theorem (**AI-NS3**) [**ICT C6-4.1, F1-4.2**]
- analyzing data to determine effective energy conservation strategies, e.g.,
  - *analyze which saves the most energy in vehicles: lowering the speed limit or modifying the internal combustion engine* (**AI–ST2, AI–STS3**) [**ICT C6–4.1, 4.3, 4.5, F3–4.1, P2–4.1**].

Communication and Teamwork

Students will:

20–D1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *use integrated software effectively and efficiently to reproduce work that incorporates data, graphics and text* (**CT–NS2**) [**P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* describe the properties of mechanical waves and explain how they transmit energy.

Outcomes for Knowledge

Students will:

20–D2.1k describe mechanical waves as particles of a medium that are moving in simple harmonic motion

20–D2.2k compare and contrast energy transmission by matter that moves and by waves

20–D2.3k define longitudinal and transverse waves in terms of the direction of motion of the medium particles in relation to the direction of propagation of the wave

20–D2.4k define the terms wavelength, wave velocity, period, frequency, amplitude, wave front and ray as they apply to describing transverse and longitudinal waves

20–D2.5k describe how the speed of a wave depends on the characteristics of the medium

20–D2.6k predict, quantitatively, and verify the effects of changing one or a combination of the variables in the universal wave equation ($v = f\lambda$)

20–D2.7k explain, qualitatively, the phenomenon of reflection as exhibited by mechanical waves

20–D2.8k explain, qualitatively, the conditions for constructive and destructive interference of waves and for acoustical resonance

20–D2.9k explain, qualitatively and quantitatively, the Doppler effect on a stationary observer with a moving source.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

20–D2.1sts explain that the goal of technology is to provide solutions to practical problems, e.g.,

- *investigate the application of acoustical phenomena in recreation, medicine, industry and technology, e.g., sonography, ultrasound, sonar, pipe organs, wind and brass instruments, noise reduction devices, noise measurement devices* (**ST1**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* describe the properties of mechanical waves and how they transmit energy.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

20–D2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues, e.g.,

- *predict the conditions required for constructive and destructive interference to occur* **(IP–NS3)**.

Performing and Recording

Students will:

20–D2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- drawing wave-front and ray diagrams **(PR–NS4) [ICT P2–4.1]**
- drawing a wave-front diagram of a two-point source interference pattern **(PR–NS4) [ICT P2–4.1]**
- performing an experiment to illustrate the phenomenon of acoustical resonance **(PR–NS2)**.

Analyzing and Interpreting

Students will:

20–D2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions, e.g.,

- determining the speed of a mechanical wave **(PR–NS3) [ICT F1–4.2, C1–4.2, F5–4.2]**, e.g.,
  - *water waves and sound waves*
- *relating changes in wavelength and frequency to the speed of the source or the receiver* **(AI–NS2) [ICT C7–4.2]**.

Communication and Teamwork

Students will:

20–D2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* **(CT–ST2) [ICT P4–4.3, F1–4.3]**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Physics 30

Physics 30 consists of four units of study:
A. Momentum and Impulse
B. Forces and Fields
C. Electromagnetic Radiation
D. Atomic Physics

Attitude Outcomes for Physics 30

Students will be encouraged to develop positive attitudes that support the responsible acquisition and application of knowledge related to science and technology. The following attitude outcomes are to be developed throughout the Physics 30 program, in conjunction with the outcomes for Knowledge, Science, Technology and Society (STS) and Skills in each unit.

Interest in Science

Students will be encouraged to:
show interest in science-related questions and issues, and confidently pursue personal interests and career possibilities within science-related fields, e.g.,

- *express interest in science and technology topics not directly related to their formal studies*
- *appreciate the usefulness of models and theories in helping to explain the natural world*
- *recognize the usefulness of being skilled at mathematics and problem solving.*

Mutual Respect

Students will be encouraged to:
appreciate that scientific understanding evolves from the interaction of ideas involving people with different views and backgrounds, e.g.,

- *consider more than one perspective when formulating conclusions or solving problems*
- *recognize that theories are developed as a result of the sharing of ideas by many scientists.*

Scientific Attitudes

Students will be encouraged to:
seek and apply evidence when evaluating approaches to investigations, problem solving and decision making, e.g.,

- *appreciate how scientific problem solving and the development of new technologies are related*
- *critically assess their opinion of the value of science and its applications*
- *appreciate the creativity and perseverance required to develop workable solutions to problems*
- *appreciate the restricted nature of evidence when interpreting observed phenomena*
- *tolerate uncertainty in providing explanations and theoretical definitions.*

Collaboration

Students will be encouraged to:
work collaboratively in planning and carrying out investigations, and in generating and evaluating ideas, e.g.,

- *evaluate the ideas of others objectively*
- *assume a variety of roles within a group, as required*
- *accept responsibility for any task that helps the group complete an activity*
- *seek the point of view of others and consider a variety of perspectives*
- *develop a willingness to try various problem-solving strategies and risk being wrong.*

Stewardship

Students will be encouraged to:
demonstrate sensitivity and responsibility in pursuing a balance between the needs of humans and a sustainable environment, e.g.,

- *develop an awareness that the application of technology has risks and benefits*
- *remain critically minded regarding the short- and long-term consequences of human action*
- *consider a variety of perspectives when addressing issues, weighing scientific, technological and ecological factors.*

Safety

Students will be encouraged to:
show concern for safety in planning, carrying out and reviewing science and technology activities, e.g.,

- *consider safety a positive limiting factor in scientific and technological endeavours*
- *keep the workstation uncluttered, with only appropriate laboratory materials present*
- *treat equipment with respect.*

Unit A: Momentum and Impulse

Themes: Change and Systems

Overview: In this unit, Newton's second law of motion is linked to the concepts of momentum and impulse.

This unit builds on:
- Physics 20, Unit A: Kinematics
- Physics 20, Unit B: Dynamics
- Physics 20, Unit D: Conservation of Energy

This unit prepares students for further study of mechanics in subsequent units and for post-secondary studies in physics. This unit will require approximately 15% of the time allotted for Physics 30.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• properties of the linear function	Pure Mathematics 10, specific outcome 4.6; Applied Mathematics 10, specific outcomes 5.1, 5.2 and 5.7
• graphing quadratic functions and solving quadratic equations	Pure Mathematics 20, specific outcomes 2.3 and 2.4; Applied Mathematics 20, specific outcomes 2.1 and 2.3
• horizontal and vertical components of vectors, and vector addition	Pure Mathematics 10, specific outcomes 6.1 and 6.2; Applied Mathematics 30, specific outcomes 5.1 to 5.4

Focusing Questions: What characteristics of an object affect its momentum? How are momentum and impulse related?

General Outcomes: There is one major outcome in this unit.

Students will:
1. explain how momentum is conserved when objects interact in an isolated system.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.
- impulse
- momentum
- Newton's laws of motion
- inertia
- elastic collisions
- inelastic collisions

General Outcome 1: *Students will* explain how momentum is conserved when objects interact in an isolated system.

Outcomes for Knowledge

Students will:

30–A1.1k define momentum as a vector quantity equal to the product of the mass and the velocity of an object

30–A1.2k explain, quantitatively, the concepts of impulse and change in momentum, using Newton's laws of motion

30–A1.3k explain, qualitatively, that momentum is conserved in an isolated system

30–A1.4k explain, quantitatively, that momentum is conserved in one- and two-dimensional interactions in an isolated system

30–A1.5k define, compare and contrast elastic and inelastic collisions using quantitative examples in terms of conservation of kinetic energy
Note: Systems of equations are not required.

Outcomes for Science, Technology and Society (Emphasis on science and technology)

Students will:

30–A1.1sts explain that technological problems often lend themselves to multiple solutions that involve different designs, materials and processes and have both intended and unintended consequences, e.g.,

- *investigate the role of impulse and momentum in the design and function of rockets and thrust systems* **(ST3)**
- *assess the role conservation laws, the concepts of impulse and inertia, and Newton's laws play in the design and use of injury prevention devices in vehicles and sports* **(ST3)**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 1: *Students will* explain how momentum is conserved when objects interact in an isolated system.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–A1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by:

- designing an experiment and identifying and controlling major variables, e.g.,
  - *demonstrating the conservation of linear momentum* **(IP–NS2)**
  - *illustrating the relationship between impulse and change in momentum* **(IP–NS2)**.

Performing and Recording

Students will:

30–A1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an experiment to demonstrate the conservation of linear momentum, using available technologies, e.g.,
  - *air track, air table, motion sensors, strobe lights and photography* **(PR–NS2, 3) [ICT F1–4.2, C1–4.2]**
- collecting information from various print and electronic sources to explain the use of momentum and impulse concepts, e.g.,
  - *rocketry and thrust systems* **(PR–ST1, 2) [ICT C1–4.1]**
  - *the interaction between a golf club head and the ball* **(PR–ST1, 2) [ICT C1–4.1]**.

Analyzing and Interpreting

Students will:

30–A1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- analyzing graphs that illustrate the relationship between force and time during a collision **(AI–NS2) [ICT C7–4.2]**
- analyzing, quantitatively, one- and two-dimensional interactions **(AI–NS3) [ICT C7–4.2]**, and, e.g., by
  - *analyzing computer simulations of one- and two-dimensional interactions* **(AI–NS3) [ICT C7–4.2, F1–4.1]**.

Communication and Teamwork

Students will:

30–A1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by

- using appropriate SI notation, fundamental and derived units and significant digits **(CT–ST2) [ICT P4–4.3, F1–4.3]***
- using the delta notation correctly when describing changes in quantities **(CT–ST2) [ICT P4–4.3, F1–4.3]***.

* To be developed throughout the course

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Unit B: Forces and Fields

Themes: Energy and Matter

Overview: In this unit, students investigate electric and magnetic forces and fields and their applications in technological devices.

This unit builds on:
- Science 9, Unit D: Electrical principles and Technologies
- Physics 20, Unit A: Kinematics
- Physics 20, Unit B: Dynamics
- Physics 20, Unit C: Periodic Motion
- Physics 20, Unit D: Conservation of Energy

This unit prepares students for further study of electromagnetic phenomena in subsequent units and for post-secondary studies in physics. This unit will require approximately 30% of the time allotted for Physics 30.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• properties of the linear function	Pure Mathematics 10, specific outcome 4.6; Applied Mathematics 10, specific outcomes 5.1, 5.2 and 5.7
• graphing quadratic functions and solving quadratic equations	Pure Mathematics 20, specific outcomes 2.3 and 2.4; Applied Mathematics 20, specific outcomes 2.1 and 2.3
• horizontal and vertical components of vectors, vector addition	Pure Mathematics 10, specific outcomes 6.1 and 6.2 ; Applied Mathematics 30, specific outcomes 5.1 to 5.4
• rewriting a formula in terms of the responding variable	Pure Mathematics 10, specific outcome 4.4; Applied Mathematics 10, specific outcome 5.1
• solving nonlinear equations	Pure Mathematics 20, specific outcome 3.1; Applied Mathematics 20, specific outcome 2.1

Focusing Questions: How is the value of the elementary charge determined? What is the relationship between electricity and magnetism? How does magnetism assist in the understanding of fundamental particles?

General Outcomes: There are three major outcomes in this unit.

Students will:

1. explain the behaviour of electric charges using the laws that govern electrical interactions
2. describe electric phenomena using the electric field theory
3. explain how the properties of electric and magnetic fields are applied in numerous devices.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.

- electric charge
- conservation of charge
- Coulomb's law
- vector fields
- electric field
- magnetic field
- electric potential difference
- moving charges in electric and magnetic fields
- charge quantization—Millikan's experiment
- electromagnetic induction

General Outcome 1: *Students will* explain the behaviour of electric charges using the laws that govern electrical interactions.

Outcomes for Knowledge

Students will:

30–B1.1k explain electrical interactions in terms of the law of conservation of charge
30–B1.2k explain electrical interactions in terms of the repulsion and attraction of charges
30–B1.3k compare the methods of transferring charge: conduction and induction
30–B1.4k explain, qualitatively, the distribution of charge on the surfaces of conductors and insulators
30–B1.5k explain, qualitatively, the principles pertinent to Coulomb's torsion balance experiment
30–B1.6k calculate, using Coulomb's law, the magnitude of the electric force on a point charge due to a second point charge
30–B1.7k determine, quantitatively, the magnitude and direction of the electric force on a point charge due to one or more other stationary point charges in a plane
30–B1.8k compare, qualitatively and quantitatively, the inverse square relationship as it is expressed by Coulomb's law and by Newton's universal law of gravitation.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–B1.1sts explain that concepts, models and theories are often used in interpreting and explaining observations and in predicting future observations, e.g.,

- *explain that the electric model of matter is fundamental to the interpretation of electrical phenomena* (**NS6a**)
- *explain that charge separation and transfer from one object to another are fundamental electrical processes* (**NS6a**)

30–B1.2sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discoveries, e.g.,

- *compare and contrast the experimental designs used by Coulomb and Cavendish, in terms of the role that technology plays in advancing science* (**ST4**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 1: *Students will* explain the behaviour of electric charges using the laws that govern electrical interactions.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–B1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues, e.g., by

- *designing an experiment to examine the relationships among magnitude of charge, electric force and separating distance between point charges* (**IP–NS2**)
- *predicting the results of an activity demonstrating charge separation and transfer* (**IP–NS3**).

Performing and Recording

Students will:

30–B1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an activity to demonstrate methods of charge separation and transfer (**PR–NS2**)
- performing an experiment to demonstrate the relationships among magnitude of charge, electric force and separating distance between point charges (**PR–NS2, 3**) [**ICT F1–4.2, C1–4.2, F5–4.2**].

Analyzing and Interpreting

Students will:

30–B1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- inferring the mathematical relationship among charge, force and separating distance from empirical evidence (**AI–NS2**) [**ICT C7–4.2**]
- using free-body diagrams to describe the electrostatic forces acting on a charge (**AI–NS1**) [**ICT F1–4.3**]
- using graphical techniques to analyze data, e.g.,
  - *curve straightening i.e., manipulate variables to obtain a straight-line graph* (**AI–NS2**) [**ICT C7–4.2**].

Communication and Teamwork

Students will:

30–B1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* describe electric phenomena using the electric field theory.

Outcomes for Knowledge

	Students will:
30–B2.1k	define vector fields
30–B2.2k	compare forces and fields
30–B2.3k	compare, qualitatively, gravitational potential energy and electric potential energy
30–B2.4k	define electric potential difference as a change in electric potential energy per unit of charge
30–B2.5k	calculate the electric potential difference between two points in a uniform electric field
30–B2.6k	explain, quantitatively, electric fields in terms of intensity (strength) and direction relative to the source of the field and to the effect on an electric charge
30–B2.7k	define electric current as the amount of charge passing a reference point per unit of time
30–B2.8k	describe, quantitatively, the motion of an electric charge in a uniform electric field
30–B2.9k	explain electrical interactions, quantitatively, using the law of conservation of energy
30–B2.10k	explain Millikan's oil-drop experiment and its significance relative to charge quantization.

Outcomes for Science, Technology and Society (Emphasis on science and technology)

Students will:

30–B2.1sts explain that the goal of technology is to provide solutions to practical problems by

- *assessing how the principles of electrostatics are used to solve problems in industry and technology, and improve upon quality of life, e.g., photocopiers, electrostatic air cleaners, precipitators, anti-static clothing products, lightning rods* (**ST1**)

30–B2.2sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discovery, e.g.,

- *explain, qualitatively, how the problem of protecting sensitive components in a computer from electric fields is solved* (**ST4**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Skill Outcomes (Focus on problem solving)

Initiating and Planning

Students will:

30–B2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues, e.g., by

- evaluating and selecting appropriate procedures and instruments for collecting data and information and for solving problems (**IP–ST3**) [**ICT C1–4.3**].

Performing and Recording

Students will:

30–B2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- plotting electric fields, using field lines, for fields induced by discrete point charges, combinations of discrete point charges (similarly and oppositely charged) and charged parallel plates (**PR–NS2**).

Analyzing and Interpreting

Students will:

30–B2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- analyzing, quantitatively, the motion of an electric charge following a straight or curved path in a uniform electric field using Newton's second law and vector addition, and conservation of energy (**AI–NS3**)
- using accepted scientific convention and expressing energy in terms of electron volts when appropriate (**AI–NS1**) [**ICT F1–4.3**]
- using free-body diagrams to describe the forces acting on a charge in an electric field (**AI–NS1**) [**ICT F1–4.3**].

Communication and Teamwork

Students will:

30–B2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 3: *Students will* explain how the properties of electric and magnetic fields are applied in numerous devices.

Outcomes for Knowledge

Students will:

30–B3.1k describe magnetic interactions in terms of forces and fields

30–B3.2k compare gravitational, electric and magnetic fields (caused by permanent magnets and moving charges) in terms of their sources and directions

30–B3.3k describe how the discoveries of Oersted and Faraday form the foundation of the theory relating electricity to magnetism

30–B3.4k describe, qualitatively, a moving charge as the source of a magnetic field and predict the orientation of the magnetic field from the direction of motion

30–B3.5k explain, qualitatively and quantitatively, how a uniform magnetic field affects a moving electric charge, using the relationships among charge, motion, field direction and strength, when motion and field directions are mutually perpendicular

30–B3.6k explain, quantitatively, uniform magnetic and electric fields affect a moving electric charge, using the relationships among charge, motion, field direction and strength, when motion and field directions are mutually perpendicular

30–B.3.7k describe and explain, qualitatively, the interaction between a magnetic field and a moving charge and between a magnetic field and a current-carrying conductor

30–B3.8k explain, quantitatively, the effect of an external magnetic field on a current-carrying conductor

30–B3.9k describe the effects of moving a conductor in an external magnetic field in terms of moving charges in a magnetic field.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–B3.1sts explain that concepts, models and theories are often used in interpreting and explaining observations and in predicting future observations, e.g.,

- *discuss, qualitatively, Lenz's law in terms of conservation of energy, giving examples of situations where Lenz's law applies* (**NS6a**)
- *investigate the origin and mechanism of the auroras* (**NS6a**)

30–B3.2sts explain that the goal of technology is to provide solutions to practical problems and that the appropriateness, risks and benefits of technologies need to be assessed for each potential application from a variety of perspectives, including sustainability, e.g.,

- *evaluate an electromagnetic technology, e.g., magnetic resonance imaging (MRI), (PET) transformers, AC and DC motors, AC and DC generators, speakers, telephones* (**ST1, 2, 7**)
- *investigate the effects of electricity and magnetism on living organisms in terms of the limitations of scientific knowledge and technology and in terms of quality of life* (**ST1, 3, 6**)

30–B3.3sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discovery, e.g.,

- *describe how technological developments were influenced by the discovery of superconductivity* (**ST4**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 3: *Students will* explain how the properties of electric and magnetic fields are applied in numerous devices.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–B3.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- designing an experiment demonstrating the effect of a uniform magnetic field on a current-carrying conductor (**IP–NS2**) [**ICT C6–4.2**]
- designing an experiment demonstrating the effect of a uniform magnetic field on a moving conductor (**IP–NS2**) [**ICT C6–4.2**], and, e.g., by
- *designing an experiment demonstrating the effect on a uniform magnetic field on a moving electric charge* (**IP–NS2**) [**ICT C6–4.2**].

Performing and Recording

Students will:

30–B3.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an experiment to demonstrate the effect of a uniform magnetic field on a current-carrying conductor, using the appropriate apparatus effectively and safely (**PR–NS2, 3**) [**ICT F1–4.2, C1–4.2, F5–4.2**]
- performing an experiment to demonstrate the effect of a uniform magnetic field on a moving conductor, using the appropriate apparatus effectively and safely (**PR–NS2, 3**) [**ICT F1–4.2, C1–4.2, F5–4.2**]
- predicting, using appropriate hand rules, the relative directions of motion, force and field in electromagnetic interactions (**PR–NS2**).

Analyzing and Interpreting

Students will:

30–B3.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- stating a conclusion based on experimental evidence that describes the interactions of a uniform magnetic field and a moving or current-carrying conductor (**AI–NS6**)
- analyzing, quantitatively, the motion of an electric charge following a straight or curved path in a uniform magnetic field using Newton's second law and vector addition (**AI–NS3**)
- analyzing, quantitatively, the motion of an electric charge following a straight path in uniform and mutually perpendicular electric and magnetic fields using Newton's second law and vector addition (**AI–NS3**)
- using free-body diagrams to describe forces acting on an electric charge in electric and magnetic fields (**AI–NS1**) [**ICT F1–4.3**].

Communication and Teamwork

Students will:

30–B3.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–NS2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Unit C: Electromagnetic Radiation

Themes: Diversity and Matter

Overview: In this unit, students study the nature and characteristics of electromagnetic radiation using the wave and photon models of light.

This unit builds on:
- Science 8, Unit C: Light and Optical Systems
- Physics 20, Unit D: Conservation of Energy

This unit prepares students for further study of electromagnetic radiation phenomena and the nature of matter in subsequent units and for post-secondary studies in physics. This unit will require approximately 25% of the time allotted for Physics 30.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• rewriting a formula in terms of the responding variable	Pure Mathematics 10, specific outcome 4.4; Applied Mathematics 10, specific outcome 5.1
• solving nonlinear equations	Pure Mathematics 20, specific outcome 3.1; Applied Mathematics 20, specific outcome 2.1

Focusing Questions: What roles do electricity and magnetism play in electromagnetic radiation? Does electromagnetic radiation have a wave or a particle nature? What experimental evidence is required to decide whether electromagnetic radiation has a wave or a particle nature?

General Outcomes: There are two major outcomes in this unit.

Students will:
1. explain the nature and behaviour of electromagnetic radiation using the wave model
2. explain the photoelectric effect using the quantum model.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.
- speed of electromagnetic radiation
- propagation of electromagnetic radiation
- reflection
- refraction
- diffraction
- interference
- total internal reflection
- Snell's law
- photoelectric effect
- Compton effect

General Outcome 1: *Students will* explain the nature and behaviour of electromagnetic radiation using the wave model.

Outcomes for Knowledge

Students will:

30–C1.1k describe, qualitatively, how all accelerating charges produce electromagnetic radiation

30–C1.2k explain the propagation of electromagnetic radiation in terms of perpendicular electric and magnetic fields that are varying with time and travelling away from their source at the speed of light

30–C1.3k explain, qualitatively, various methods of measuring the speed of electromagnetic radiation

30–C1.4k calculate the speed of electromagnetic radiation, given data from a Michelson-type of experiment

30–C1.5k describe, quantitatively, the phenomena of reflection and refraction (including total internal reflection)

30–C1.6k describe, quantitatively, simple optical systems consisting of one lens or one mirror

30–C1.7k describe, qualitatively, diffraction, interference and polarization

30–C1.8k describe how the results of Young's double-slit experiment support the wave model of light

30–C1.9k solve double-slit and diffraction grating problems using, e.g., $\lambda = \frac{xd}{nl}$, $\lambda = \frac{d \sin \vartheta}{n}$

30–C1.10k describe how refraction supports the wave model of electromagnetic radiation using, e.g., $\frac{\sin \vartheta_1}{\sin \vartheta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

30–C1.11k compare and contrast the visible spectra produced by diffraction gratings and triangular prisms.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–C1.1sts explain that scientific knowledge is subject to change as new evidence comes to light and as laws and theories are tested and subsequently restricted, revised or reinforced, e.g.,

- *Poisson's spot, speed of light in water, sunglasses, photography, liquid crystal diodes* **(NS4)**

30–C1.2sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discovery, e.g.,

- *describe measurement procedures for the speed of electromagnetic radiation (EMR)*
- *investigate the design of greenhouses cameras, telescopes, solar collectors, fibre optics, effects of frequency and wavelength on the growth of plants*
- *investigate the use of interferometry techniques in the search for extra-solar planets* **(ST4)**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 1: *Students will* explain the nature and behaviour of electromagnetic radiation using the wave model.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–C1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by
- predicting the conditions required for diffraction to be observed (**IP–NS3**)
- predicting the conditions required for total internal reflection to occur (**IP–NS3**)
- designing an experiment to measure the speed of light (**IP–NS2**) [**ICT C6–4.2**].

Performing and Recording

Students will:

30–C1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by
- performing experiments to demonstrate refraction at plane and uniformly curved surfaces (**PR–NS2**)
- performing an experiment to determine the index of refraction of several different substances (**PR–NS4**) [**ICT P2–4.1**]
- carrying out an investigation to determine the focal length of a thin lens or of a curved mirror (**PR–NS4**) [**ICT P2–4.1**]
- observing the visible spectra formed by diffraction gratings and triangular prisms (**PR–NS2**)
- performing an experiment to determine the wavelength of a light source in air or in a liquid using a double-slit or a diffraction grating (**PR–NS2, 3**) [**ICT F1–4.2, F5–4.2, C1–4.2**]
- performing an experiment to verify the effects on an interference pattern due to changes in any one or more of the following variables: wavelength, slit separation or screen distance (**PR–NS2, 3**) [**ICT F1–4.2, F5–4.2, C1–4.2**].

Analyzing and Interpreting

Students will:

30–C1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by:
- deriving the mathematical representation of the law of refraction from experimental data (**AI–NS2**) [**ICT C7–4.2**]
- using ray diagrams to describe an image formed by a thin lens or a curved mirror (**AI–NS1**) [**ICT F1–4.3**]
- demonstrating the relationship among wavelength, slit separation and screen distance using empirical data and algorithms (**AI–NS6**).

Communication and Teamwork

Students will:

30–C1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by
- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions*, e.g.,
  - *drawing ray diagrams* (**CT–NS2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* explain the photoelectric effect using the quantum model.

Outcomes for Knowledge

Students will:

- 30–C2.1k define the photon as a quantum of electromagnetic radiation and calculate its energy
- 30–C2.2k classify the regions of the electromagnetic spectrum by photon energy
- 30–C2.3k describe the photoelectric effect in terms of the intensity and wavelength of the incident light and surface material
- 30–C2.4k describe, quantitatively, photoelectric emission using concepts related to the conservation of energy
- 30–C2.5k describe the photoelectric effect as a phenomenon that supports the notion of the wave-particle duality of electromagnetic radiation
- 30–C2.6k explain, qualitatively and quantitatively, the Compton effect, applying the laws of mechanics and of conservation of momentum and energy to photons, as another example of wave-particle duality.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–C2.1sts explain that scientific knowledge and theories develop through hypotheses, the collection of evidence through experimentation and the ability to provide explanations, e.g.,

- describe how Hertz discovered the photoelectric effect while investigating electromagnetic waves
- *describe how Planck used energy quantization to explain blackbody radiation* (**NS2**)

30–C2.2sts explain that concepts, models, and theories are often used to interpret and explain observations and to predict future observations, e.g.,

- *investigate and report on the development of early quantum theory* (**NS6**)

30–C2.3sts explain that the goal of technology is to provide solutions to practical problems, e.g.,

- *analyze, in general terms, the functioning of various technological applications of photons to solve practical problems, e.g., automatic door openers, burglar alarms, light meters, smoke detectors, X-ray examination of welds, crystal structure analysis* (**ST1**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* explain the photoelectric effect using the quantum model.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–C2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- predicting the effect on photoelectric emission of changing the intensity and/or frequency of the incident radiation or the material of the photocathode (**IP–NS3**), and, e.g., by
- *designing an experiment to measure Planck's constant, using either a photovoltaic cell or a light-emitting diode* (**IP–NS2, 4**) [**ICT C6–4.2; C1–4.3**].

Performing and Recording

Students will:

30–C2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information, e.g., by

- *performing an experiment to demonstrate the photoelectric effect* (**PR–NS2**)
- *measuring Planck's constant, using either a photovoltaic cell or a light-emitting diode (LED)* (**PR–NS2, 3**) [**ICT F1–4.2, F5–4.2, C1–4.2**].

Analyzing and Interpreting

Students will:

30–C2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- analyzing and interpreting empirical data from an experiment on the photoelectric effect, using a graph that is either drawn by hand or computer generated (**AI–NS2, 4**) [**ICT C6–4.2, C1–4.3**]
- determining the wavelength of microwaves, using data provided from demonstrations, e.g.,
  - *interference patterns of television signals or in microwave ovens* (**AI–NS3, 4**).

Communication and Teamwork

Students will:

30–C2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–NS2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Unit D: Atomic Physics

Themes: Energy and Matter

Overview: In this unit, students study the development and modification of models of the structure of matter.

This unit builds on:
- Science 9, Unit E: Space Exploration
- Physics 20, Unit D: Conservation of Energy
- Physics 30, Unit B: Forces and Fields
- Physics 30, Unit C: Electromagnetic Radiation

This unit prepares students for further study of the nature of matter in post-secondary studies in physics. This unit will require approximately 30% of the time allotted for Physics 30.

Links to Mathematics:

The following mathematics topics are not considered as prerequisites.

Topics:	These topics may be found in the following courses:
• rewriting a formula in terms of the responding variable	Pure Mathematics 10, specific outcome 4.4; Applied Mathematics 10, specific outcome 5.1
• solving nonlinear equations	Pure Mathematics 20, specific outcome 3.1; Applied Mathematics 20, specific outcome 2.1
• properties of the exponential function	Pure Mathematics 20, specific outcome 6.4; Pure Mathematics 30, specific outcomes 2.4 and 2.5; Applied Mathematics 20, specific outcomes 2.3 to 2.5

Focusing Questions: How is the atom organized? How can a model of the atom and the nucleus be subjected to experimental tests? How does knowledge of the internal structure of the atom lead to the development of applications of energy supply and to the technology of diagnostic imaging?

General Outcomes: There are four major outcomes in this unit.

Students will:
1. describe the electric nature of the atom
2. describe the quantization of energy in atoms and nuclei
3. describe nuclear fission and fusion as the most powerful energy sources in nature
4. describe the ongoing development of models of the structure of matter.

Key Concepts: The following concepts are developed in this unit and may also be addressed in other units at other levels. The intended level and scope of treatment is defined by the learning outcomes.
- charge-to-mass ratio—Thomson's experiment
- classical model of the Atom (Rutherford, Bohr)
- spectra: continuous, line emission and line absorption
- energy levels (states)
- deBroglie hypothesis
- quantum mechanical model
- half-life
- nuclear decay
- nuclear reactions
- Standard model of matter

General Outcome 1: *Students will* describe the electric nature of the atom.

Outcomes for Knowledge

Students will:

30–D1.1k describe matter as containing discrete positive and negative charges

30–D1.2k explain how the discovery of cathode rays contributed to the development of atomic models

30–D1.3k explain J.J. Thomson's experiment and the significance of the results for both science and technology

30–D1.4k explain, qualitatively, the significance of the results of Rutherford's scattering experiment in terms of scientists' understanding of the relative size and mass of the nucleus and the atom.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–D1.1sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discoveries, e.g.,

- *analyze how the identification of the electron and its characteristics is an example of the interaction of science and technology* (**ST4**)
- *analyze the operation of cathode-ray tubes and mass spectrometers* (**ST4**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–D1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- identifying, defining and delimiting questions to investigate, e.g.,
  - *What is the importance of cathode rays in the development of atomic models?* **(IP–NS1)**
- evaluating and selecting appropriate procedures and instruments for collecting evidence and information, including appropriate sampling procedures, e.g.,
  - *using electric and magnetic fields to determine the charge-to-mass ratio of the electron* **(IP–NS4) [ICT C1–4.3]**.

Performing and Recording

Students will:

30–D1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- performing an experiment, or using simulations, to determine the charge-to-mass ratio of the electron **(PR–NS2, 3) [ICT F1–4.2, F5–4.2, C1–4.2]**.

Analyzing and Interpreting

Students will:

30–D1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- determining the mass of an electron and/or ion, given appropriate empirical data **(AI–NS3)**
- derive a formula for the charge-to-mass ratio that has input variables that can be measured in an experiment using electric and magnetic fields (**AI–NS6**).

Communication and Teamwork

Students will:

30–D1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) **[ICT P4–4.3, F1–4.3]**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 2: *Students will* describe the quantization of energy in atoms and nuclei.

Outcomes for Knowledge

Students will:

30–D2.1k explain, qualitatively, how emission of electromagnetic radiation by an accelerating charged particle invalidates the classical model of the atom

30–D2.2k describe that each element has a unique line spectrum

30–D2.3k explain, qualitatively, the characteristics of, and the conditions necessary to produce continuous, line emission and line absorption spectra

30–D2.4k explain, qualitatively, the concept of stationary states and how they explain the observed spectra of atoms and molecules

30–D2.5k calculate the energy difference between states, using conservation of energy, and the observed characteristics of an emitted photon

30–D2.6k explain, qualitatively, how electron diffraction provides experimental support for the de Broglie hypothesis

30–D2.7k describe, qualitatively, how the two-slit electron interference experiment shows that quantum systems like photons and electrons have indeterminate properties, contrary to intuition.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–D2.1sts explain that scientific knowledge and theories develop through hypotheses, the collection of evidence through experimentation and the ability to provide explanations, e.g.,

- *investigate and report on the use of line spectra in the study of the Universe and the identification of substances* (**NS2**)
- *investigate how empirical evidence guided the evolution of the atomic model* (**NS2**)

30–D2.2sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discoveries, e.g.,

- *investigate and report on the application of spectral or quantum concepts in the design and functioning of a practical device such as street lights, advertising signs, electron microscopes, lasers* (**ST4**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–D2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems, and issues by

- predicting the conditions necessary to produce line emission and line absorption spectra (**IP–NS3**)
- predicting the possible energy transitions in the hydrogen atom, using a labelled diagram showing energy levels (**IP–NS3**).

Performing and Recording

Students will:

30–D2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- observing line emission and line absorption spectra (**PR–NS3**) [**ICT F1–4.2, F5–4.2, C1–4.2**]
- observing the representative line spectra of selected elements (**PR–NS3**) [**ICT F1–4.2, F5–4.2, C1–4.2**]
- using library and electronic research tools to compare and contrast, qualitatively, the classical and quantum models of the atom (**PR–NS1**) [**ICT C7–4.2**].

Analyzing and Interpreting

Students will:

30–D2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- identifying elements represented in sample line spectra by comparing them to representative line spectra of elements (**AI–NS4**) [**ICT C3–41**].

Communication and Teamwork

Students will:

30–D2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 3: *Students will* describe nuclear fission and fusion as the most powerful energy sources in nature.

Outcomes for Knowledge

Students will:

30–D3.1k describe the nature and properties, including biological effects, of alpha, beta, and gamma radiation

30–D3.2k write nuclear equations, using isotope notation, for alpha, beta-negative and beta-positive decays

30–D3.3k perform simple, nonlogarithmic half-life calculations

30–D3.4k use the law of conservation of charge and mass number to predict the particles emitted by a nucleus

30–D3.5k compare and contrast the characteristics of fission and fusion reactions

30–D3.6k relate, qualitatively and quantitatively, the mass defect of the nucleus to the energy released in nuclear reactions using Einstein's concept of mass-energy equivalence.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–D3.1sts explain that the goal of science is knowledge about the natural world, e.g.,

- *investigate the role of nuclear reactions in the evolution of the universe—nucleosynthesis, stellar expansion and contraction* **(NS1)**
- *investigate annihilation of particles and pair production* **(NS1)**

30–D3.2sts explain that the products of technology are devices, systems and processes that meet given needs, but that these products cannot solve all problems and that the appropriateness, risks and benefits of technologies need to be assessed for each potential application from a variety of perspectives, including sustainability, e.g.,

- *assess the risks and benefits of air travellers' exposure to cosmic radiation, dental X-rays, radioisotopes used as tracers, food irradiation, use of fission or fusion as a commercial power source, nuclear and particle research* **(ST6, 7)**.

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 3: *Students will* describe nuclear fission and fusion as the most powerful energy sources in nature.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–D3.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- predicting the penetrating characteristics of decay products (**IP–NS3**).

Performing and Recording

Students will:

30–D3.2s conduct investigations into the relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- *researching and reporting on scientists who contributed to the understanding of the structure of the nucleus* (**PR–NS1**) [**ICT C7–4.2**].

Analyzing and Interpreting

Students will:

30–D3.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- graphing data from radioactive decay and estimating half-life values (**AI–NS2**) [**ICT C7–4.2**]
- identifying isotopes that will be stable, and those that will undergo alpha, beta or beta positive decay, from a modern periodic table (**PR–NS1**) [**ICT C7–4.2**]
- interpreting common nuclear decay chains (**AI–NS6**)
- graphing data for radioactive decay and inferring an exponential relationship between measured radioactivity and elapsed time (**AI–NS2**) [**ICT C7–4.2**]
- comparing the energy released in a nuclear reaction to the energy released in a chemical reaction on the basis of energy per unit mass of reactants (**AI–NS3**).

Communication and Teamwork

Students will:

30–D3.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 4: *Students will* describe the ongoing development of models of the structure of matter.

Outcomes for Knowledge

Students will:

30–D4.1k explain how the analysis of particle tracks contributed to the discovery and identification of the characteristics of sub-atomic particles

30–D4.2k explain, qualitatively, why high-energy particle accelerators are required to study sub-atomic particles

30–D4.3k describe the modern model of the proton and neutron as being composed of quarks

30–D4.4k compare and contrast the first generation elementary fermions and their antiparticles in terms of charge and energy (mass-energy)

30–D4.5k describe beta-positive (β^+) and beta-negative (β^-) decay using first generation elementary fermions.

Outcomes for Science, Technology and Society (Emphasis on the nature of science)

Students will:

30–D4.1sts explain that concepts, models and theories are often used in interpreting and explaining observations and in predicting future observations, e.g.,

- *research and report the development of models of matter* (**NS6a**)

30–D4.2sts explain that scientific knowledge may lead to the development of new technologies and new technologies may lead to scientific discoveries, e.g.,

- *investigate how high-energy particle accelerators contributed to the development of the standard model of matter* (**ST4**).

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.

General Outcome 4: *Students will* describe the ongoing development of models of the structure of matter.

Skill Outcomes (Focus on scientific inquiry)

Initiating and Planning

Students will:

30–D4.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by

- predicting the characteristics of elementary particles from images of their tracks in a bubble chamber with an external magnetic field (**IP–NS2**).

Performing and Recording

Students will:

30–D4.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by

- *researching, using library and electronic resources, the relationships between the fundamental particles and the interactions they undergo* (**PR–NS1**) [**ICT C7–4.2**].

Analyzing and Interpreting

Students will:

30–D4.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by

- analyzing, qualitatively, particle tracks for subatomic particles other than protons, electrons and neutrons (**AI–NS2**) [**ICT C7–4.2**]
- writing beta and beta-positive decay equations, identifying the elementary fermions involved (**PR–NS4**) [**ICT P2–4.1**]
- using hand rules to determine the nature of the charge on a particle (**AI-NS6**)
- using accepted scientific convention and expressing mass in terms of giga electron volts per c^2 (GeV/c^2) when appropriate (**AI–NS1**) [**ICT F1–4.3**].

Communication and Teamwork

Students will:

30–D4.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results, e.g.,

- *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions* (**CT–ST2**) [**ICT P4–4.3, F1–4.3**].

Note: Some of the outcomes are supported by examples. The examples are written in italics and **do not form part of the required program** but are provided as an illustration of how the outcomes might be developed.